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CHEMICAL RESEARCH & DEVELOPMENT DEPARTMENT

C. R. D. D. REPORT No. 308/R/47

A STUDY OF INFRA RED RADIANT HEATING PLANT IN RELATION TO DRYING, PARTICULARLY FOR EXPLOSIVES AND PROPELLANTS.

BY

P. A. WHITE AND J.H. HOPKINS.

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A STUDY OF INFRA RED RADIANT HEATING PLANT IN RELATION TO DRYING, PARTICULARLY FOR EXPLOSIVES AND PROPELLANTS

BY

P.A. WHITE AND J.H. HOPKINS

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Source: Chemical Research & Development Department Report. C.R.D.D. Report No. 308/R/47. Eval: A-1.

Area Reported On: Gt. Britain. Subject: INFRA-RED DRYING OF EXPLOSIVES AND PROPELLANTS.

Reference: (DIRECTIVE, CORRESPONDENCE, PREVIOUS REPORT, ETC., IF APPLICABLE.)

SUMMARY: ENTER CAREFUL SUMMARY OF REPORT, CONTAINING SUBSTANCE SUCCINCTLY STATED. ANSWER QUESTIONS WHERE, WHEN, WHAT, HOW, HOW MANY, AND GIVE DATE OF EVENT. IN A FINAL ONE SENTENCE PARAGRAPH GIVE SIGNIFICANCE. BEGIN TEXT ON PAGE 2.

BRITISH SUMMARY:

Experimental work was carried out in a pilot scale incandescent lamp type of oven, designed after consultation with the G.E.C. (General Electric Company) Research Department, and in a convection oven of similar proportions, special methods being used for surface temperature and air humidity measurements. The main experiments were conducted towards comparison of mechanism of drying and drying rates in the types of oven. Work was also done on the effect of different variables on the rate of drying in the radiation oven, and on the maximum temperatures reached by different substances, under different conditions in such an oven. It is shown that the equation Drying Rate = K $(H_s - H_a)$ where H_s is the saturation humidity for the surface temperature and H_a is the air humidity holds for both radiation and convection ovens, the value of K being the same for each oven. The different rates of drying for the two ovens are therefore due to the raising of the surface temperature by the radiation from the lamps.

COMMENT:

This method of drying has wide application in the U.S. A copy of this report is inclosed for direct transmittal to Picatinny Arsenal.

JOHN L. ATKINS,
Lt. Col. Ordnance,
Tech. Liaison Officer.

APPROVED
FOR THE MILITARY ATTACHE:

[illegible],
Lt. Col. FA.,
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A STUDY OF INFRA-RED RADIANT HEATING IN RELATION TO DRYING PARTICULARLY FOR EXPLOSIVES AND PROPELLANTS

S.No.9

Reference C R Temp 3/9/1/1

SUMMARY

During the last 10 years a considerable development has occurred of the use of high temperature radiant energy in industrial plants for heating, drying etc. The radiation is supplied from incandescent lamps or direct fired gas panels.

The work reported here was undertaken to assess the possible value of these new processes in explosive industry applications.

Experimental work was carried out in a pilot scale incandescent lamp type of oven, designed after consultation with the G.E.C. Research Department, and in a convection oven of similar proportions, special methods being used for surface temperature and air humidity measurements.

The main experiments were conducted towards comparison of mechanism of drying and drying rates in the types of oven. Work was also done on the effect of different variables on the rate of drying in the radiation oven, and on the maximum temperatures reached by different substances, under different conditions in such an oven.

It is shown that the equation

$$\text{Drying Rate} = K\,(H_s - H_a)$$

where H_s is the saturation humidity for the surface temperature and H_a is the air humidity holds for both radiation and convection ovens, the value of K being the same for each oven. The different rates of drying for the two ovens are therefore due to the raising of the surface temperature by the radiation from the lamps.

A large number of drying experiment results are tabulated in Table II. From these are obtained the curves showing the approximately linear variation of drying rate with humidity. They also show that drying rates are approximately proportional to intensity of radiation (number of lamps). Thus, the average constant drying rate for sand with 18 lamps is 6.47 grms/min/sq.ft and with 10 lamps is 2.7 grms/min/sq.ft. Drying rates also depend on the nature of the material being dried, being in the order of their absorptivities. This is shown in the following table:-

Material	Drying Rate	Absorptivity (Ref.No.2
Sand	6.75	(Refractories .65 to .85)
Water	8.08	.95 to .963
Water coated with carbon black	8.82	Up to .97 - carbon black

Similarly the maximum temperatures reached by materials in the radiation oven appear to depend/approximately on their absorptivity as shown in the following table:-

Material	Maximum Temperature (18 lamps)	Maximum Temperature (10 lamps)
Sand	150	95
Carbon Black	195	112
Ammonium nitrate	156	95
Picric Acid		83
Guanidine Nitrate		79

The presence of a nitro-group in a compound does not appear to make it more absorbent of infra-red radiation as was claimed in a patent some time ago.

Calculations of relative costs (on the basis of lbs steam/lb water removed) involved in the use of radiant ovens and convection ovens for different drying processes have been made. Results are:-

Western Cartridge Co. Infra Red installation for drying ball powder	13.6 lbs steam/lb water removed
Experimental oven for surface drying of sand	5.4 " " /lb " "
" " for total drying of sand	7.1 " " " " "
" " for total drying of RDX/TNT	24-28 lbs steam/lb " "

Convection ovens for surface drying are usually considered efficient if they use about 2 lbs.steam/lb water removed.

Experimental Quinan Stove drying of RDX/TNT

It is concluded that:-

(a) The mechanism of infra-red radiation drying is essentially the same as with ordinary convection ovens, but the extra radiant energy by raising the temperature of the surface of the material considerably above the wet bulb temperature produces higher drying rates for the same air temperatures.

(b) In the evaporation of water, the rate is dependent on the humidity of the surrounding air.

(c) The drying rate is dependent on the material which is being dried approximately in accordance with their absorptivities.

(d) The temperatures attained by dry materials in the infra red oven depend on the radiant intensity and the nature of the substance. It is possible to arrange temperatures suitable for explosives practice without fear that the presence of impurities will seriously vary the temperatures obtained.

(e) The incandescent lamp type of oven seems quite suitable for explosives, on safety grounds.

(f) Among the advantages of this type of plant for drying are high drying rates; smaller plant and space; time saving; labour saving; reduced explosive limits; adaptability; very little standby heat loss.

The great[illegible] disadvantage is the high power cost - calculated as equivalent to 13.6 lbs steam/lb water removed for one industrial plant, 5.4 lbs steam/lb water removed for the most efficient drying, and 28.8 lbs steam/lb water removed for drying RDX/TNT in the experimental oven.

/It

It is recommended that:-

(a) In consideration of drying problems in the explosives or propellants production the possibility of using infra-red radiant heating should be included, particularly since some of its advantages would be of considerable value in war time.

(b) Since so much of the drying of explosives and propellants takes place in the falling rate period and so little theoretical knowledge is available of the mechanism of such drying further investigation of this problem is desirable.

(c) Further work should be carried out on the drying of actual explosives and propellants where it is considered that drying efficiency might be improved.

A STUDY OF INFRA-RED RADIANT HEATING

PLANT IN RELATION TO DRYING, PARTICULARLY

FOR EXPLOSIVES AND PROPELLANTS

I. INTRODUCTION

The drying of solids may be brought about by a number of methods such as pressing, centrifuging or vaporisation. By far the most generally used is the vaporisation of water into the air and this process is accelerated by heating the material being dried and/or the air which passes over it.

In general it may be said that drying rate can be increased or drying time reduced by increasing the difference between water vapour pressure saturation value at the surface of the material and the vapour pressure in the main bulk of the drying air. The most normal method of effecting this in practice is by raising the temperature of the material being dried or of the air passing over it. The efficient supply of heat to the material or the air thus provides a fundamental problem in the design of an efficient drying process.

Three methods of supplying heat are generally recognised: conduction, convection and radiation. In any type of heater or dryer all three methods of heating will almost certainly be involved. In all the most usual drying plants such as tunnel driers, tray driers, rotary driers etc., convection, either natural or forced is the principal method of supplying heat to the material being dried. Wherever the material is in sight of a part of the plant at a higher temperature than itself, however, radiation will also be a contributory factor in the heating. The higher the temperature of the plant, the greater will be the radiation effect in proportion to the convection effect (in accordance with Stefan's well known fourth power law). If the temperature of the radiating surface is raised to a very high value (say 2,500°C) and no special steps are taken to supply extra convective heat, the heat supplied to the material will be almost entirely by radiation.

The rate of heat transfer by convection is dependent upon many factors but, as is well known it is restricted by the stagnant films of fluid (air or liquid) which surround all solid surfaces. The rate of heat transfer by radiation is dependent mainly on the temperature of the emitting body and the absorption coefficient of the material being heated. It suffers no appreciable restriction from the air and if high radiating temperature sources are used, the rate of heat transfer can be made high. Heat losses will also be high owing to the extremely high temperatures of emission.

In Table I, comparative figures for convection and radiation heat transfer are given (Ref.No.1).

Natural convection Oven Temp.	Rate of Heat Transfer ¤	Infra Red Lamp Radiation 2500°C source, corrected for losses. Rate of Heat Transfer.
100°C	47 watts/sq.ft	
150°C	86 " "	
200°C	129 " "	
250°C	176 " "	400 watts/sq.ft

¤ To body at 20°C.

These figures are understood to be taken from the performance of typical installations of both types but clearly the basis of comparison is arbitrary. e.g. Reducing the size of the radiating source, as by reduction in the number of lamps to a given area will reduce the radiation intensity. Or, by using forced convection in a convection oven at 150°C and 30 ft/sec. air, the rate of heat transfer increases from 86 to 380 watts/sq.ft.

/It

It will be seen that it is possible to design heating installations of comparable performance with the more usual types of heating or drying plant by utilising radiant heat alone and not in association with or as an addition to convection and drying, provided sources of the correct temperature and density of radiation can be obtained.

The earliest attempt in this direction is indicated by a patent brought out by F.J.Govan and the Ford Motor Co. in 1935, in which he suggested the application of infra-red radiant energy in the baking of enamel on to motor car bodies. Since that time a considerable development of this idea has taken place, and plants are now available which utilise three types of radiant energy source.

(a) The incandescent lamp, usually of tungsten filament in a gas filled bulb operating at filament temperatures of about 2500°A.

(b) Low temperature (about 750°C) sheathed wire type radiant heating element.

(c) Direct fired, gas heated panels - black emitting or incandescent.

The incandescent lamp would seem to be the method most well established and it is claimed (Ref.No.3) that among the uses to which such lamps have been put in America are:-

Baking enamel on metal surfaces.
Drying cardboard.
Softening thermoplastic sheets.
Expanding aluminium pistons.
Dehydration of glue.
Drying of textiles.
Drying of TNT and smokeless powder.

The use of these methods of heating and drying has been greatly extended in industry during the war years, particularly where demands for reduced heating time and floor space have been of importance.

II. OBJECTS OF THE TRIALS

The work which this report describes was undertaken with the object of assessing the possible value of these new heating and drying processes in explosive industry applications. It was carried out by investigation of the following aspects of radiation drying.

(a) Investigation of the mechanism of radiant heat drying in comparison with other methods of drying.

(b) Determination of the temperatures reached by materials being dried, how they can be controlled and the effect of temperature on the rate of drying.

(c) Effect of the nature of the substance and its colour etc on temperatures reached and rate of drying.

(d) Assessment of practical and economic aspects of the use of radiant heating with explosives etc.

III. METHODS EMPLOYED

(a) For determination of drying rates by radiation heating.

A small scale incandescent-lamp radiation oven was designed after consultation with Mr. Connell of the G.E.C. Research Department and is shown in Figs 1, 2 and 3. It consists of two trough reflector lamp banks, supplied by Messrs G.E.C., each trough containing nine industrial infra-red lamps, each of 250 watts. These troughs were supported by a rectangular framework (3' x 2' x 1'6" high), polished aluminium sheets being fixed to the vertical sides so as to reflect as much of the radiation as possible on to the material being dried.

/The

The base of the framework consisted of a masonite platform which could be adjusted to any distance from the lamps. A rectangular hole was cut in the middle of the platform, large enough to allow a rectangular aluminium pan 12" x 8" to have a free vertical movement. This pan was supported by a fine wire, from a balance placed above the troughs. The balance finally used was of Vendome & Hart design, capable of directly indicating weight differences of 1/8 grm. This arrangement enabled the loss of weight of a material as it dried, easily to be determined.

The measurement of the temperature of a material subjected to radiation from a high-temperature source is clearly difficult. Measurement of both wet and dry bulb temperatures of the air and of the temperature at the surface of the material being dried is, however, very important in investigating drying phenomena and the following procedures were adopted.

(b) Humidity.

The apparatus for wet and dry bulb temperature measurement is shown in Fig.6 and in Fig 3, fixed in position. It was devised so that a current of air from inside the apparatus could be drawn over two thermometers fixed in a small vessel, one of the thermometer bulbs being wetted continually by water from a well outside the vessel. This apparatus was placed below the radiation oven, shielded from radiation and rendered non-conducting. With heat gains and losses thus at a minimum, the apparatus gave a continuous reading of the humidity of the bulk of air in the oven. The current of air was too small appreciably to affect the air movement in the oven.

(c) Temperature of Material.

The temperature at the surface of the material being dried was determined by measuring the temperature at various points below the surface in a special apparatus, and extrapolating to the surface. The apparatus (shown in Fig.5) consisted of a steel cylinder 2" diameter with four pairs of holes, on diameters, at distances of 1/8", 1/4", 3/8" and 1/2" from the top. Calibrated thermocouples were placed across these holes and insulated from the cylinder, as shown. The apparatus was inserted through a suitable hole in the base of the radiation oven, so that the surface of the material was irradiated in the same way as the main material being dried.

Plots of temperature against depth are given in Fig.7.

To check on the accuracy of this method the experiment was carried out with T.N.T., the number of lamps and the distance from the lamps being adjusted until the surface of the T.N.T. only just melted. The curves in this case are also shown (curve B) and it will be seen that the extra polation is reasonably accurate. (Melting point of T.N.T. 80°C)

(d) Free Convection Drying Rates.

For purposes of comparison, a free convection oven was also used in some drying experiments. This oven was made of practically the same size as the radiation oven and was heated by means of a bank of steam pipes down each side of the oven. Drying rates were measured by the same means of a rectangular pan suspended from the beam of a balance outside the oven. This apparatus is shown in Fig.4. Temperature at the surface of materials being dried was in this case, measured by inserting a thermocouple just below the surface, since the difficulty of a large amount of radiation upsetting the instrument does not arise.

(e) Distribution of Temperature in Radiant Heat Oven.

Since the sources of radiation in the radiant heat oven are the filaments of the lamps, it might be expected that temperatures directly under the lamps would be higher than at points under the gaps between the lamps in spite of the effect of the reflecting surfaces.

Any large variation in the energy falling on different parts of the material being dried might of course, have serious consequences in the drying of materials inflammable at high temperatures.

This variation was investigated by welding a thermocouple to the under side of a small (about 1/2" dia.) disc of brass and using this disc to measure the energy at various points along the base of the oven. It may be assumed that the temperature reached by the disc (or the millivoltmeter reading of the thermocouple) is representative of the energy incident upon it. Slits were cut in the base in two directions at right angles, and the thermocouple disc moved along these slits, the thermocouple wire passing out through the base. The millivoltmeter reading was taken at the various points marked in Fig.12, which gives the results, the values of intensity being obtained as the ratio of the millivoltmeter reading at that position to the maximum value for that set of readings.

IV. RESULTS

(a) Drying Rates.

The main series of experiments carried out in the infra-red oven and, for comparison, in the convection oven were concerned with the drying of wet sand or the evaporation of water. A few runs were also carried out with RDX/TNT. The more important measurements determined during these runs are given in Table II. They include the "constant Rate" of drying i.e. the rate of drying during the period in which the drying rate remains constant and the critical moisture content which is the moisture content of the material when the drying rate begins to fall off. The total drying time is also given. The experimental runs were carried out under various different conditions of bed depth, number of lamps, and atmospheric humidity, as indicated.

(b) Temperature Measurement.

The method of measurement of surface temperature has been described. In Fig.8 typical plots of variation of temperature with time during a drying run in the oven is given. It will be seen that the temperature rises to a practically constant value during the constant rate drying period and then rises further eventually to a second maximum. Fig.8. is for the radiation oven and Fig.8 (a) for the convection oven. A series of results of maximum temperatures obtained with different substances under different conditions of number of lamps etc. are given in Table III.

(c) Distribution of Temperature over Platform.

The results obtained in experiments on the distribution of temperature over the platform of the radiation oven are given in Fig. 12 in which thermocouple readings in millivolts are plotted in relation to lamp positions when all, and one half of the lamps are used.

V. DISCUSSION OF RESULTS.

(a) Mechanism of Infra Red Drying.

The theoretical considerations underlying the process of drying are given in the appendix to this report. They will therefore only be dealt with in a general fashion in introducing the results obtained in this experimental work.

The process of drying of any material usually takes place in four stages; as shown graphically in fig.10:-

(a) the initial heating up period - AB-normally of short duration;
(b) the constant rate drying period -BC- in which the rate of drying remains constant and continues to do so until the "critical" moisture content is reached;
(c) the initial falling rate period, CD, approximating to a linear relation between rate of drying and free moisture content

/and

and

(d) DO - the falling rate period in which the rate of drying is gradually reduced until the moisture content reaches its equilibrium value.

A typical drying curve between weight of material being dried and time is shown in Fig.49 and it is from this that Fig.50 is derived. These curves are drawn up from results obtained in Run No.S.10.

The general explanation of this type of curve is as follows:-

In the initial heating up period, A.B., heat received by the material is used partly as sensible heat in raising the temperature of the material and to an increasing extent for evaporation. If the heating is continued, there is a temperature at which the heat supplied will be equal to the latent heat of evaporation at that temperature. No further temperature rise, or change in the rate of evaporation occurs and the drying rate is therefore constant; hence the constant rate period B.C. As the rate of evaporation is dependent on the surface area, there will be a period, C.D. when the moisture only partly covers the surface, the evaporating area being gradually reduced as drying proceeds. When the surface is dry, further moisture removal will occur by movement of moisture either as liquid or vapour from the interior of the material up to the surface. The actual mechanism of this movement is still the subject of considerable controversy, diffusion under concentration gradients and capillary movement being the principal theories. No satisfactory treatment of this part of the drying process exists. This is unfortunate since a large amount of the drying in cases of substances such as RDX/TNT and propellants is diffusion drying. A fuller examination of the problem would probably be amply repaid by resultant economies effected in drying costs. That such curves are obtained when drying in the infra-red oven is evidence that the mechanism of drying is essentially the same as by normal convection methods, and the effect of the radiation is to raise the temperature of the surface of the material being dried. The rate of drying under "constant Rate" conditions is given by the expression:-

$$\frac{dw}{d\theta} = K\,A\,(H_s - H_a) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where: $\frac{dw}{d\theta}$ = rate of evaporation of moisture.
K = Diffusion constant.
A = Area of surface.
H_s, H_a = Humidity (lb water vapour/lb dry air) of air at the surface of the material and in the main bulk respectively.

Under ordinary convection drying conditions, the surface temperature is at approximately the wet bulb temperature of the air. The air is saturated at the surface and $(H_s - H_a)$ cannot be varied except by increasing the temperature or dryness of the drying air. The Diffusion constant can be altered by altering the air velocity and this forms a valuable way of increasing drying rates.

If radiant heating is used however, the surface temperature can be raised considerably above the wet bulb temperature of the air. A heat balance calculated on the basis of the radiant energy input being equal to the latent heat of evaporation plus heat transferred from solid to the air gives the expression:-

$$\frac{L_s}{S}(H_s - H_a) = (T_a - T_s) + \frac{pc}{h_c}(T_r^4 - T_s^4) \quad \ldots\ldots\ldots \quad (2)$$

Where: L_s = latent heat of evaporation.
T_a, T_s, T_r = temperature of air, solid surface and radiating surface, respectively.
p = absorptivity of surface.
c = radiation constant.
h_c = surface coefficient of heat flow.
S = humid heat of wet air.

(See Appendix)

/No

No direct calculations can be made from this expression because of the absence of any satisfactory value for hc. but it will be seen that the presence of the radiation term, $p_c\ (T_r^4 - T_s^4)$ indicates that if temperatures and humidity of the air in two installations, convection and radiation were the same, the values of H_s and T_s in the latter would be higher. That means that the temperature of the surface of the material being dried would be raised considerably above the wet bulb temperature of the air.

From these theories of drying and some of the results obtained, we can calculate approximately what the difference in drying rates should be in the radiation and convection oven.

e.g. Consider Run No.S.16 and Run No.C.O.4 shown in Figs.8 and 8(a) for radiation and convection ovens respectively.

Figures obtained for surface temperatures during the constant rate period average at 59.5°C and 49°C respectively.

∴ Humidity at surface (at saturation) in these cases is : .1488 and .0819 lbs water/lb dry air.
Humidity in the main bulk of the air (obtained by taking wet and dry bulb figures to a psychrometric chart) is .014 and .033 lbs water/lb dry air.

From equation (1), the constant rate is given by

$$\frac{dw}{d\theta} = K\ A\ (H_s - H_a)$$

Since the two installations are essentially the same except for the method of heating, one might expect the value of K to be the same and the drying rates would be proportional to $(H_s - H_a)$. The values of $(H_s - H_a)$ for radiation and convection ovens in this case are respectively .1348 and .0489 lbs/lb dry air. Now the drying rate in the radiation oven for run S.16 is 2.4 grms/min. determined by the slope of the drying curve (constant rate portion). The rate of drying in the convection oven (run No.C.O.4) should therefore be .87 grs/min.

The value obtained in practice is seen, from the slope of the curve to be .92 grs/min.

This is excellent agreement and confirms the view that in radiant ovens the mechanism of the constant drying process is the same as in the convection oven except in so far as the radiant energy increases the temperature at the surface of the material being dried.

No similar quantitative analysis can easily be made of the falling rate periods but an inspection of the drying curves shown in Fig.8 and 8(a) for the two cases will show that approximately the same ratio of about 2:1 holds for the final drying after the constant rate period.

The first part of the falling rate depends on the same considerations as the constant rate period and it is therefore to be expected that the same ratio of drying rates would obtain.

That the overall falling rates are in about the same ratio indicates that, in the case of sand, at least the mechanism of diffusion drying is not different in the case of infra-red drying.

(b) <u>Effect of Humidity</u>

From Table II taking the values of humidity and "constant" drying rate and plotting them separately for sand, water and water covered with carbon black on the surface we obtain the plots shown in Fig.11.

It appears from this that in the case of water, or water of which the surface is coated with carbon black, there is approximately a linear relation

/between

between the rate of drying (evaporation) and humidity, within the range considered here. With sand, however, no such direct relation appears to exist. This may be due to the occurrence of experimental errors such as variation in smoothness of surface or incidence to radiation, or voltage to the equipment, which can exist in the sand experiments, giving rise to variations in drying rate masking any regular humidity effect. The cause of such variations appears to merit further experiment.

(c) Effect of Colour - Nature of Material etc.

In Fig.11 the experimental relation between humidity and drying rate is shown for water, and for water the surface of which is coated with carbon black. The two lines are approximately parallel but that for water whose surface is coated with carbon black is higher than for pure water, by about 12%.

Similarly the constant drying rates for sand are appreciably less than for water - averaging about 25% less.

This is explained by the difference in absorptivity of the different substances. The greater percentage of the radiation from the lamps incident on the surface, absorbed by the surface with high absorptivities will cause higher surface temperatures, higher values of the driving force (H_s-H_a) and, therefore higher drying rates. The absorptivities concerned here are:-

Water	-	.95 to .963
Carbon Black	-	up to .97
Refractories	-	.65 to .85

This result gives rise to two conclusions.

(1) The efficiency of an infra-red oven will be affected by the absorptivity of the material being dried. In any given installation therefore efforts should be made to increase the absorptivity in order to extract the highest possible efficiency from the plant.

(2) The claim of a recent patent that infra-red heating could be particularly effective with nitro bodies owing to greater absorption is only true in so far as the absorptivity of such materials are high. Since the absorptivity of water itself is as high as .95, and for the large majority of materials (other than polished metals) is over .7, this is not a factor of very great importance, at least in the constant rate period.

(d) Temperature Reached by Dry Materials in Infra-Red Oven.

In any consideration of the use of infra-red drying ovens for explosives or propellant drying, it is clearly of importance to know what temperatures may be reached by materials in the dry state.

As is shown by the curves in Fig.7. the highest temperature appears to be at the surface of the material being dried. In Fig.8 is shown how the surface temperature varies with time during a drying run. After an initial heating up period, followed by an almost constant period throughout the constant rate drying period, the temperature rises, eventually tending to a maximum. Maximum surface temperatures thus obtained under different conditions and with different materials are given in Table III.

Some conclusions which may be drawn from these results are

(1) Reduction of the number of lamps, reduces the maximum temperature obtained and by suitable adjustment of the number of lamps, practically any temperature can be obtained for a given material. The apparatus may therefore be brought to within the range/required for any given material.

/(2)

TABLE II

Run No.	No. of Lamps	Depth of Bed	% Initial Moisture	Humidity Lbs of Moisture/ lb of Dry Air	Constant Rate Grms. water per mins	Total time of Drying Mins	% Critical Moisture Content	Air Temperatures Dry Bulb °F	Wet Bulb °F
SAND									
2	18	¼"	12.5	0.011	6.45	21	2.96	-	-
3	"	"	16.2	0.009	6.90	30	3.40	-	-
4	"	"	8.9	0.010	5.50	17		-	-
5	"	"	20.3	0.008	7.45	26	4.2	-	-
6	"	"	9.15	0.006	6.30	20	2.1	-	-
7	"	"	16.3	0.007	7.15	25	3.5	-	-
8	"	"	16.2	0.008	6.81	21	2.9	-	-
9	"	"	18.5	0.009	6.89	26	3.5	-	-
10	"	"	13.9	0.0085	7.23	49	2.9	-	-
13	"	"	16.0	0.009	6.83	23	3.5	-	-
S1	"	⅜"	17.3	0.024	6.78	69	3.25	158	99
S2	"	"	16.4	0.021	6.65	63	2.82	151	93
S3	"	"	17.3	0.019	6.10	72	3.84	141	90
S4	"	"	16.5	0.019	6.80	65	2.9	147	91
S5	"	"	16.8	0.026	7.15	59	4.65	150	98
S6	"	"	15.7	0.029	5.60	70	3.45	138	95
S7	"	"	16.1	0.029	6.80	66	2.63	155	100
S8	"	"	16.8	0.033	5.25	86	5.40	118	94.5
S9	"	"	19.2	0.035	5.60	85	5.50	136	100
S10	"	"	18.4	0.029	7.20	67	5.50	163	101
S12	"	"	17.5	0.031	7.20	60	3.84	160	101
S13	"	"	18.1	0.038	7.05	66	4.36	162	103
S14	10	"	15.9	0.020	3.05	119	3.70	106	83
S15	"	"	11.5	0.016	2.63	99	3.54	95	77
S16	"	"	6.45	0.013	2.43	109	2.52	105	77
S17	18	"	10.00	0.023	5.93	70	3.84	148	94
RDX/TNT									
1	10	⅜"	6.3	0.007	1.05	319+	4.42	69	57
2	"	"	7.1	0.007	0.66	225+	4.90	74	62
3	"	"	6.6	0.008	0.70	165+	3.18	66	57

TABLE II (Continued)

Run No.	No. of Lamps	Depth of Water Ins	Humidity Lbs of Water Vapour/lb of Dry Air	Constant Rate Grms. Water Per Min *	Air Temperatures Dry Bulb °F	Wet Bulb °F
Water						
W1	18	0.4-0.2	0.032	7.65	133	97
W2	"	0.5-0.2	0.023	8.66	143	92
W3	"	0.5-0.2	0.022	8.90	139	91
W4	"	0.4-0.2	0.031	8.65	116	90
W5	"	0.4-0.2	0.021	7.90	140	89
W6	"	0.4-0.2	0.043	6.70	133	104
W7	"	0.4-0.2	0.035	8.83	165	105
W8	"	0.4-0.1	0.038	9.20	156	107
W9	"	0.5-0.3	0.050	8.08	150	111
W10	"	0.4-0.2	0.030	9.25	160	101
W11	"	0.4-0.2	0.062	7.27	144	114
W12	"	0.4-0.2	0.032	9.27	158	101

Run No.	Depth of Bed	% Initial Moisture	Humidity Lbs of Water Vapour/lb of Dry Air	Constant Rate Grms.Water Per Min *	Total Time of Drying Mins	% Critical Moisture Content	Air Temp. Over Pan °C
CO.1	3/8"	18.6	0.020	0.67	400	-	75
CO.2	"	13.3	0.035	0.72	393	3.70	77
CO.3	"	16.7	0.033	0.72	-	-	76
CO.4	"	13.9	0.033	0.92	410	3.33	88

* From suspended pan, 2/3 sq.ft in area.

≠ Time to dry to 0.1% moisture.

TABLE III

MAXIMUM TEMPERATURES °C REACHED IN INFRA-RED OVEN.

Material	Temp.with 18 lamps (670 watts/sq.ft)	Temp.with 10 lamps (386)
Carbon Black	195	112
Ammonium Nitrate	156	95
Sand	150	95
Picric Acid		83
Guanidine Nitrate		79

(2) Different materials reach different maximum temperatures under otherwise constant conditions. Such differences are explicable as due to differences in absorptivities of the surfaces concerned.

(3) As the differences in temperature reached by different materials is comparatively small and appears to be due to no other effect than different absorptivities of materials, the possibility of development of hot spots due to foreign elements in the material being dried can be discounted as being of a dangerous nature.
In further explanation here, it should be pointed out that the absorptivity of a material depends on the wavelength of the energy radiant upon it. It is equal to the emissivity of the material if the radiation is black body, and the emissivity is a physical constant of any material. In actual fact the spectral energy distribution of an infra-red lamp is practically black body so that no abnormally high absorptivity due to selective absorption over particular wavelengths emitted will be obtained with lamp heating. In other words the temperature reached by a body with an emissivity of (say) .95 cannot be greatly exceeded by any other body, whatever the specific absorbing wavelengths may be.

(4) It will be noted that the maximum temperature obtained with picric acid is below that for carbon black and sand. This result, also lends no support to the theory that nitro bodies are good absorbers of infra-red radiation and would therefore be particularly suitable for such driers.

(e) Variation In Intensity of Radiation Over Platform.

The results of this investigation, given in Fig.13 show that the variation of intensity of radiation over the surface of the platform is very small, except near the edges, even when only one half of the lamps for which the reflecting surfaces were designed, are used. This will result in:-

(a) An efficient use of the whole oven under the lamps being made.

(b) Practically constant drying rates over that part of the surface which would be used and, therefore, minimum overall drying times.

(c) Practically constant temperatures attained so that the oven can be worked quite satisfactorily at temperatures very near to melting or other critical points.

V. DISCUSSION OF PRACTICAL & ECONOMIC ASPECTS OF THE USE OF INFRA-RED OVENS FOR EXPLOSIVES ETC.

From the technical aspects of the use of radiant ovens which have been discussed in previous sections of this report, it is clear that this type of oven, whether used for heating or drying, functions in just the same way as the normal convection oven except that the amount of radiation is very much greater, with corresponding considerable rise of surface temperatures and drying rates.

Whether such ovens can or should be used in explosive or propellants practice, therefore, will be decided by practical and economic reasons.

The most important practical consideration is that of safety. Gas fired radiation ovens, since they are normally fired by direct flame would need considerable re-design before they would be suitable for explosives or propellants The incandescent lamp-type of oven, suitably designed has no such objection. Suitable protection of electrical gear and safeguards against lamp breakage would be necessary and control of part of the lamp circuit through the temperature of the material being dried would be desirable. There should be no difficulty about uneven temperatures either due to variation in intensity under the lamps or the presence of foreign materials.

It is interesting to note that an installation of this sort has been

/employed

employed by the Western Cartridge Co, East Alton, Illinois, U.S.A. since 1942, for the drying of ball powder, without any fire or other mishap having occurred.

Most other practical considerations have an affect on the economy of the process and this will now be considered.

ADVANTAGES

(1) The greatest advantage of radiation heating is the high drying rates that can be obtained, without high air temperatures. This gives rise to various direct advantages such as:-

(a) Smaller plant and space;
(b) considerable time saving (of direct advantage particularly in war time);
(c) reduced labour costs, in so far as attention to the drying process is required for a smaller time;
(d) considerably reduced stocks in process and therefore reduced explosive limits and quicker throughput.

(2) The method is well adapted to continuous working without undue heat loss. Interlock between conveyor and lamps can be made an additional safeguard against excessive baking.

(3) The standby loss is small since heat is available immediately the lamps are switched on. This is of particular importance when a dryer is serving a batch manufacturing process.

(4) It is very easy, in a continuous oven, to vary the spacing of the lamps such that more or less heating is provided at the points where they are needed, e.g. a high intensity at constant rate period.

(5) The design and conversion of lamp ovens for many different purposes is relatively simple - a big factor in the adaptibility which is necessary for wartime munitions production.

DISADVANTAGES

(1) The higher drying rates associated with the radiation oven are only obtained by raising the temperature of the surface of the material being dried. Equally high drying rates could be obtained in convection ovens by suitably adjusting the air temperature and humidity. It is therefore not suitable for materials sensitive to the temperatures necessary for high drying rates.

(2) The power costs for the operation of the radiation oven are high. The figure quoted by Western Cartridge Co. for the drying of ball powder is .196 KW hr/lb dry powder for the removal of 8% water. This, re-calculated on the assumption of electricity costs of $\frac{1}{2}$d/KW.hr and steam costs of 7/6d/1,000 lbs (an average figure for wartime operation of Ordnance factories) is equivalent to 13.6 lbs steam/lb of water removed.

In our own experimental oven (which at full intensity should be a very efficient installation), the cost during the "constant rate" or fastest drying of sand is equivalent (on the same basis) to 5.4 lbs steam/lbs water removed.
The cost for complete drying of sand (including the slower, falling rate period is approximately 7.1 lbs steam/lb water removed. The cost for complete drying of RDX/TNT - in which the efficiency must be less owing to the reduced intensity necessary to keep down surface temperatures and in which most of the drying is in the slower falling rate period, - is 24 - 28 lb steam per lb water removed.
Now the figure used for steam costs, is not low and the use of cheaper steam, or bi-product steam would throwthe economic balance in the direction of considerably higher lbs steam/lb water removed, i.e.even further reduce the relative efficiency.

/While

While it is difficult to give exactly comparable figures for convection ovens which themselves are of many types and of varying efficiencies figures are quoted of $1\frac{1}{2}$ - 2 lb steam/lb water removed for surface or constant rate drying and 3-5 lbs/lb water removed for slow drying of timber etc. as normal practical figures.

(3) A figure determined for the total drying of RDX/TNT in a modified Quinan stove was 4 lbs steam/lb water removed.

No general conclusion can be reached with regard to the relative efficiency of radiant and convection ovens and it is clear that the factors which have been mentioned would each need to be weighed seriously for each drying problem encountered in deciding which method was the most economic. The fact that the infra-red oven possesses a number of advantages which are of particular importance in war time might outweigh a slight loss in operating costs, when considered in connection with explosives. On the other hand, in general industry, it is believed that for other than very special applications, infra-red drying is only likely to be used for materials where very high temperature drying can be tolerated, such as the quick drying of very thin films of paint.

VI. CONCLUSIONS

1. The mechanism of infra-red radiation drying is essentially the same as with ordinary convection ovens but the extra radiant energy, by raising the temperature of the surface of the material, produces considerably higher drying rates for the same air temperatures.

2. A variation of drying rate with humidity of the air is obtained in the drying of water, but no regular relation has been obtained with sand.

3. The drying rate in the infra-red oven is dependent on the material upon which the radiation falls, the order of drying rates being the same order as of the absorptivities of the materials used.

4. The temperatures attained by dry materials in the infra-red oven depend upon the nature of the substance, and the radiation intensity. The radiation intensity can be arranged so that temperatures suitable for explosives are obtained at the surface. The effect of impurities or foreign body inclusions would be too small seriously to increase local temperatures.

5. The variation of intensity of radiation over a bed irradiated by a bank of lamps is very small except for the extreme edges so that even temperatures and drying rates over the bed can be expected.

6. There appears to be no reason why the incandescent lamp oven should not be used for the drying of explosives or propellants, on safety grounds, provided normal safeguards for electrical mechanisms and temperature control are provided.

7. Any decision on the use of the infra-red radiation oven for practical drying problems would need to be decided for the individual case after weighing the various economic factors concerned. Among the most important of these, are, in brief:-

   (a) High drying rates with resultant smaller plant and space, time saving, labour saving and reduced stocks and explosive limits.
   (b) Easy adaptability for continuous working.
   (c) Very little standby heat loss.
   (d) Easy adjustment of design of oven to different drying problems, i.e. ready adaptability.
   (e) Higher drying rates only obtained by increasing surface temperatures of materials being dried and therefore only really satisfactory for quick high temperature drying.
   (f) Appreciably higher direct operating costs.

VII. RECOMMENDATIONS

1. In consideration of drying problems in explosives or propellants production the possibility of using infra-red radiant heating should be included. It will be more particularly applicable for materials which can stand drying temperatures above 70°C. and some of its advantages would be of considerable value in war time.

2. A considerable amount of the drying of explosives and propellants takes place as "diffusion" or "falling-rate" drying. Very little is known about such drying either practically or theoretically and further work carried out in this field would most certainly be amply rewarded by economies in drying costs which should result. This would apply to both radiation and other types of drying.

3. One unsatisfactory feature of results discussed here is that no regular relation was found between drying rates for sand and air humidity. For the sake of clarifying the theoretical issues, this work might be carried on further.

4. With the semi-plant equipment now available for rapid determination of the value of infra-red drying for any particular problem, it is recommended that further work be carried out with a number of materials where it is considered that drying efficiency requires improvement.

REFERENCES

1. "The Application of Radiant & Inductive Heating to Industrial Processes" E. Connell. G.E.C. Journal Vol.XIII. 1944.

2. "Drying" Section 13. Perry's "Chemical Engineers Handbook".

3. "Mechanism & Rate of Drying by near Infra-Red Radiation", Stout Baird & Caplan. Tr.A.I. Chem.E. 1945.

4. "The Drying of Granular Solids". Cealgske & Hougen. Tr.A.I.Chem.E.1937.

5. "Approximate Diffusion Calculations for the Falling Rate Phase of Drying" W.B.Van Arsdel Tr.A.I.Chem.E.1947.

6. "Ball Powder Manufacture". Chemical Engineering Jan. 1946.

APPENDIX

THEORETICAL CONSIDERATIONS OF THE PROCESS OF DRYING (REF. 2.)

When a material is dried by any normal process, the drying can usually be divided into four periods - shown in Fig.10.

(1) The initial heating period AB.
(2) The constant rate period - when the rate of drying is constant - BC.
(3) The first part of the Falling Rate Period - when the rate of drying is controlled by the effective wet surface area - CD.
(4) The second part of the falling rate period - when the controlling factor is the rate of diffusion of moisture through the material.

1. The Initial Heating Period

Heat passed into the material being dried, by convection from the circulating air and/or by radiation from surrounding surfaces is used for warming up the material and for converting moisture into water, to an increasing extent as the temperature rises.

In a radiation oven,

$$\frac{dQ}{d\theta} = \rho V c \frac{dt}{d\theta} + L \frac{dw}{d\theta} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where dQ = heat transferred to the material by radiation in time $d\theta$, ρ, V and c are density, volume and specific heat respectively of the material

dt = rise in temperature in time $d\theta$
dw = loss of moisture from the material in time $d\theta$
L = latent of water at the temperatures concerned.

This equation cannot be solved in any simple manner, but the initial heating period is, anyway, of relatively small importance.

2. The Constant Rate Period

At the point B, a steady state has been reached, in which the heat transferred to the material is used to convert the moisture driven off into vapour and to warm the surrounding air

$$\frac{dQ}{d\theta} = L \frac{dw}{d\theta} + \frac{dQ_1}{d\theta} \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where $\frac{dQ_1}{d\theta}$ = heat passing from the solid to the surrounding air.

Now the rate of drying is proportional to the area of drying surface and to the difference between the humidity (lbs air/lb dry air) at the surface and in the main bulk of material, the proportionality constant being called the Diffusivity Constant.

$$\text{i.e.} \quad \frac{dw}{d\theta} = K A (H_s - H_a) \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

K = Diffusivity Constant.
A = Area of surface of material being dried.
$H_s H_a$ = Humidity of air at surface and in main bulk of air.

NOTE - H_s is the saturation humidity for the temperature at the surface of the solid.

The heat transferred to the air, from the solid is given by the normal heat transfer equation.

$$\frac{dQ_1}{d\theta} = h_c A (T_s - T_a) \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where h_c = heat transfer coefficient
T_s, T_a = temperatures at material surface and in bulk of air.

Further $$\frac{h_c}{K} = S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

/Where

Where S = humid heat of the wet air (i.e. specific heat of the air plus the water it contains).

From equations (2) (3) (4) and (5) we may derive

$$\frac{L_s}{S}\ (H_s - H_a) = \frac{1}{h_c . A}\ \frac{dQ}{d\theta} + (T_a - T_s)$$

Now the radiant energy falling on a surface of area A may be expressed by

$$\frac{dQ}{d\theta} = A.p.c\ (T_r{}^4 - T_s{}^4) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

p = absorptivity of solid surface
c = radiation constant
T_r = temperature of radiating surface.

$$\text{i.e.}\quad \frac{L}{S}\ (H_s - H_a) = \frac{pc}{h_c}\ (T_r{}^4 - T_s{}^4) + (T_a - T_s) \quad \ldots\ldots \quad (7)$$

3. The Falling Rate Period - 1st Part

During this period it is assumed that the area of wet surface gradually diminishes, and the wet surface remaining behaves as during the constant rate period. If, at any time the wet area is A and A is the total area, while the corresponding moisture contents are F and Fc, and it is assumed that the wet area is proportional to the free moisture content,

$$\text{Then} \qquad A = \frac{A_1}{F_c}\ .\ F$$

and the drying rate is then given by: $\frac{dw}{d\theta} = K\ \frac{A^1}{F_c}\ .\ F\ (H_s - H_a)$

Thus the rate is proportional to the free moisture content.

4. The Falling Rate Period - 2nd Part

Eventually a time is reached when the controlling factor is no longer evaporation from the surface, but diffusion of moisture from the inside of the material.

No satisfactory mathematical analysis of this drying process exists. The classical work of Sherwood assumed that water diffusion from inside a solid obeyed similar laws to the flow of heat except that the driving force was difference in concentration rather than difference in temperature. The mathematical expression in this case is:-

$$\frac{\partial C}{\partial \theta} = K\ \frac{\partial^2 C}{\partial\ X^2}$$

Where C = concentration of moisture
K = Diffusion constant
θ = Time
X = Distance

For an infinite slab, this gives the expression

$$\frac{F_1 - F}{F_1 - F_c} = \frac{8}{\pi^2}\left[e^{-\left(\frac{\pi}{2}\right)^2 \tau} + \frac{1}{9}\, e^{-9\left(\frac{\pi}{2}\right)^2 \tau} + \ldots\ldots \right]$$

Where $\tau = \frac{4K\theta}{D^2}$ and F_1, F and F_o are moisture contents initially, at time t, and at equilibrium, AND D = SLAB THICKNESS.

Integration of this equation has been carried out for many special cases and since it provides a good approximation to many practical cases, it can be used with success in many drying problems.

In an effort to extend the validity of this analysis, more recent work has been carried out by a number of workers, one line (Ref.No.5) being the inclusion of a variable diffusivity factor in accordance with experimentally determined relationships between diffusivity and concentration. The method of calculation is exceedingly laborious and complicated.

/A

A quite different approach to the problem of Falling Rate Drying has been made by Ceaglske & Hougen (Ref.4.) assuming that movement of water in a solid is dependent on capillary forces. There is strong evidence that such an interpretation cannot be overlooked in some cases, but again the experimental work required and the complicated calculations make any use of this theory impracticable for normal drying problems.

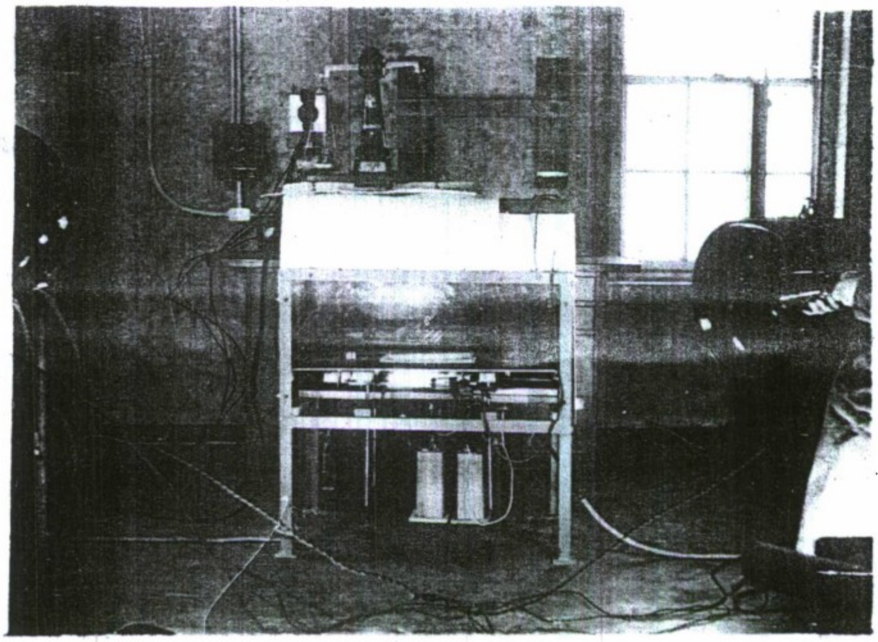


FIG. 1: INFRA-RED OVEN - WITH SIDE REMOVED.

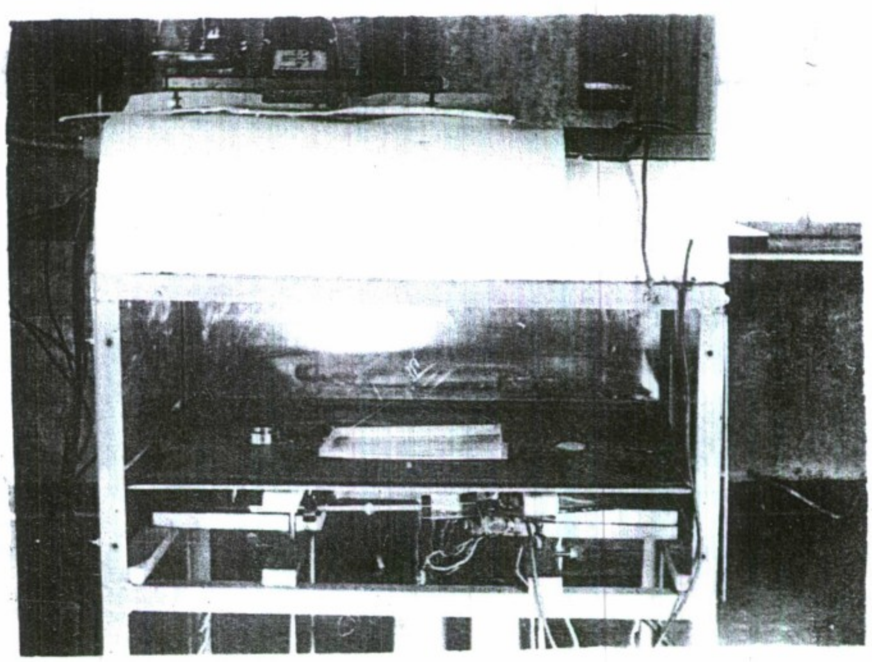


FIG. 2: INFRA-RED OVEN - DETAIL OF PLATFORM.

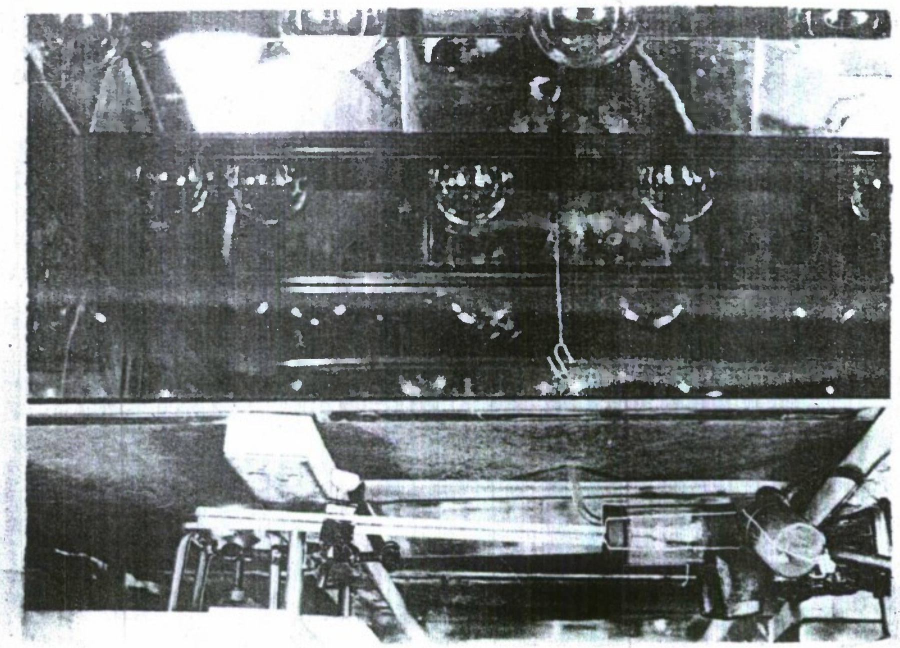


FIG. 3: INFRA-RED OVEN - SHOWING LAMPS AND HUMIDITY DETERMINATION APPARATUS.

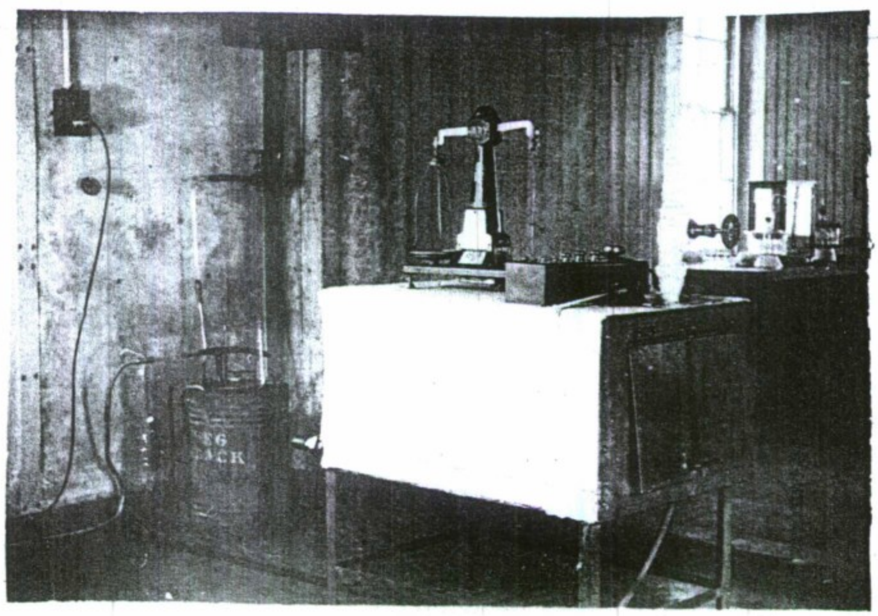


FIG. 4: CONVECTION DRYING OVEN.

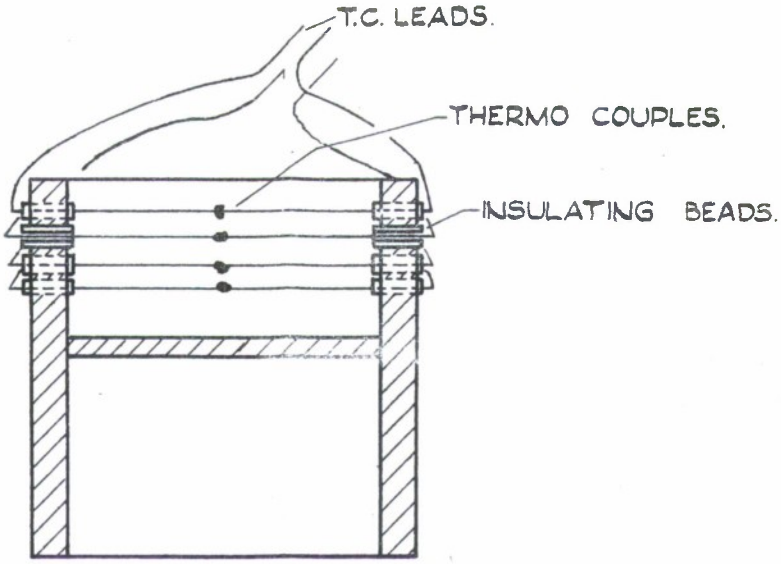


FIG. 5.

APPARATUS FOR MEASURING SURFACE TEMPERATURES.

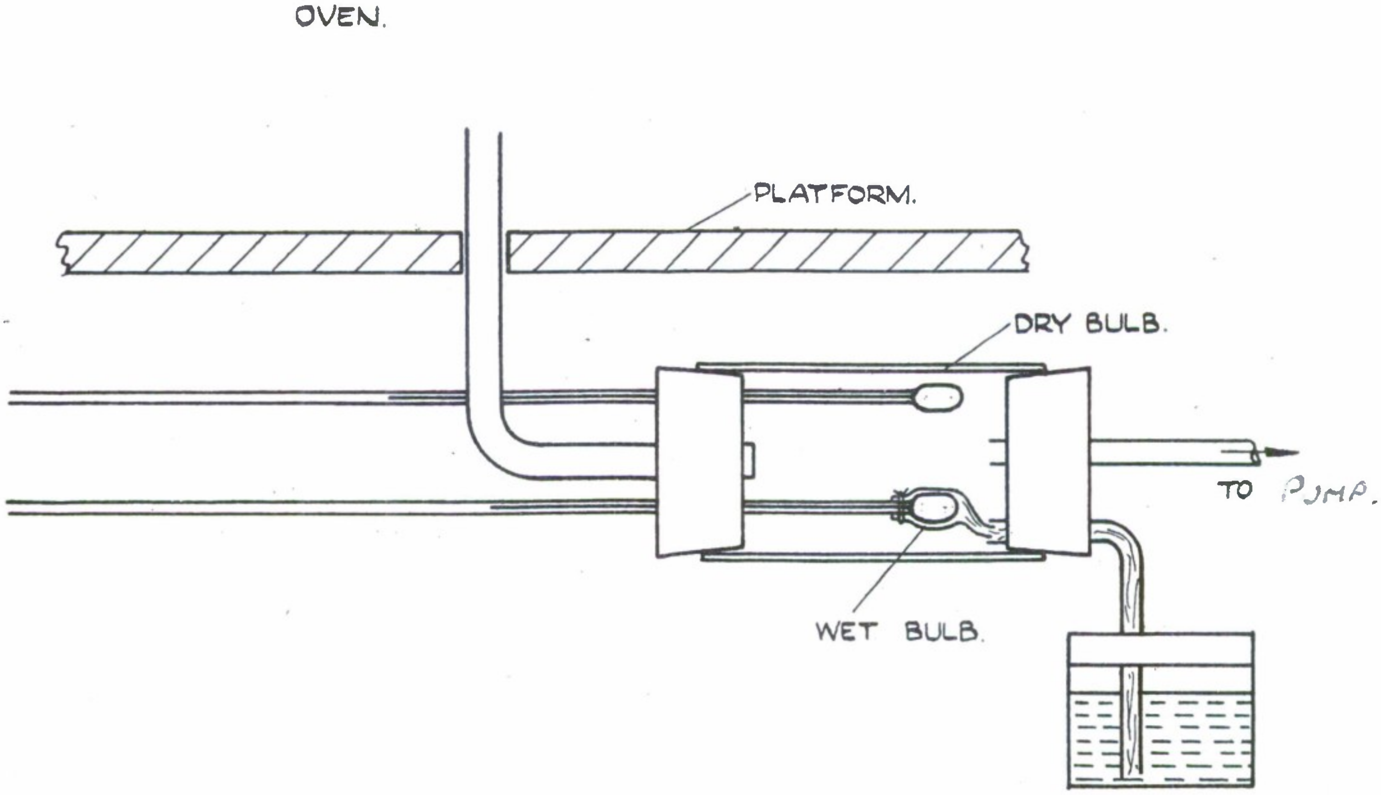


FIG. 6.

HUMIDITY MEASURING APPARATUS.

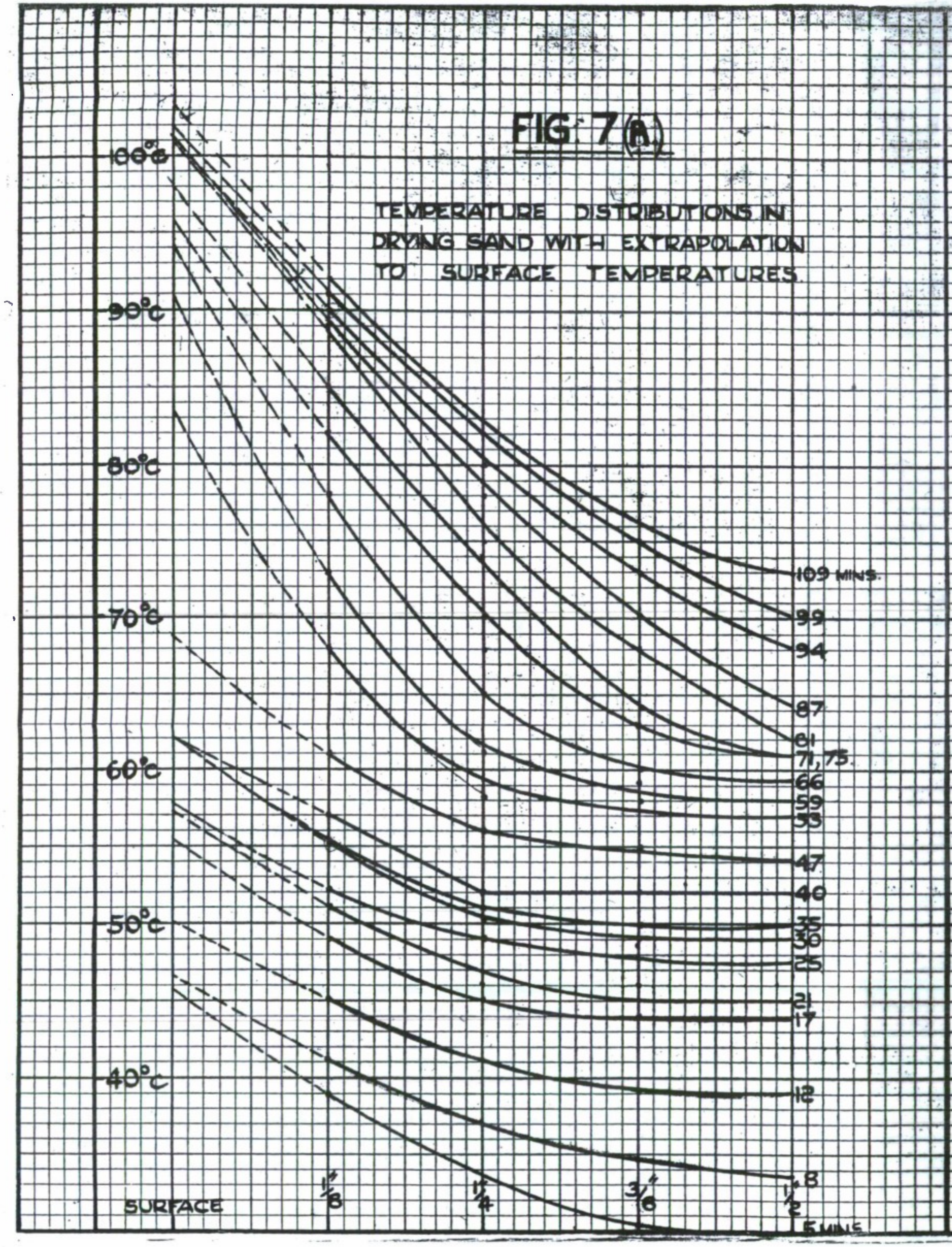


FIG 7(A)

TEMPERATURE DISTRIBUTIONS IN DRYING SAND WITH EXTRAPOLATION TO SURFACE TEMPERATURES.

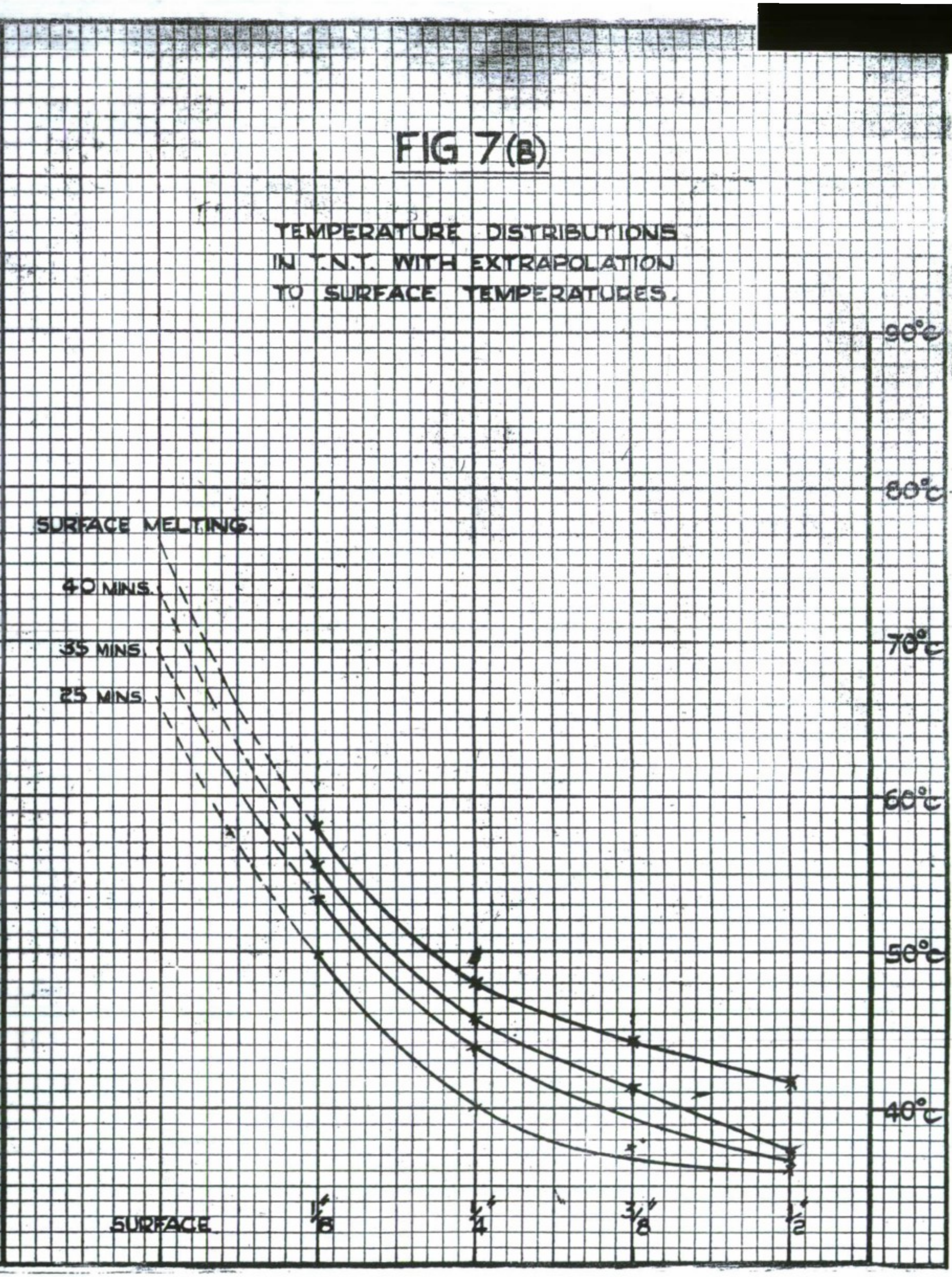
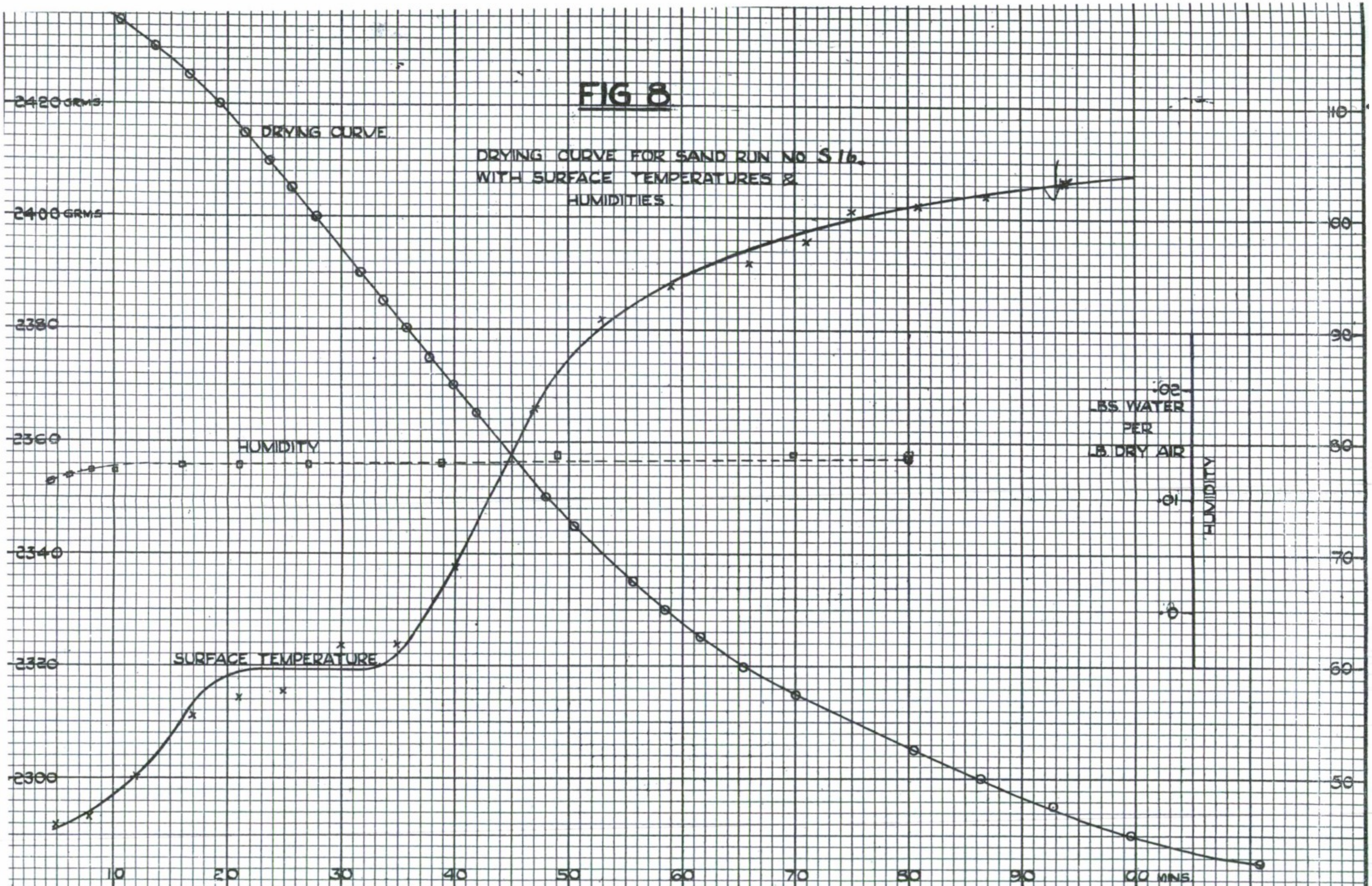


FIG 7(B)

TEMPERATURE DISTRIBUTIONS IN T.N.T. WITH EXTRAPOLATION TO SURFACE TEMPERATURES.

FIG 8

DRYING CURVE FOR SAND RUN No S 16,
WITH SURFACE TEMPERATURES &
HUMIDITIES



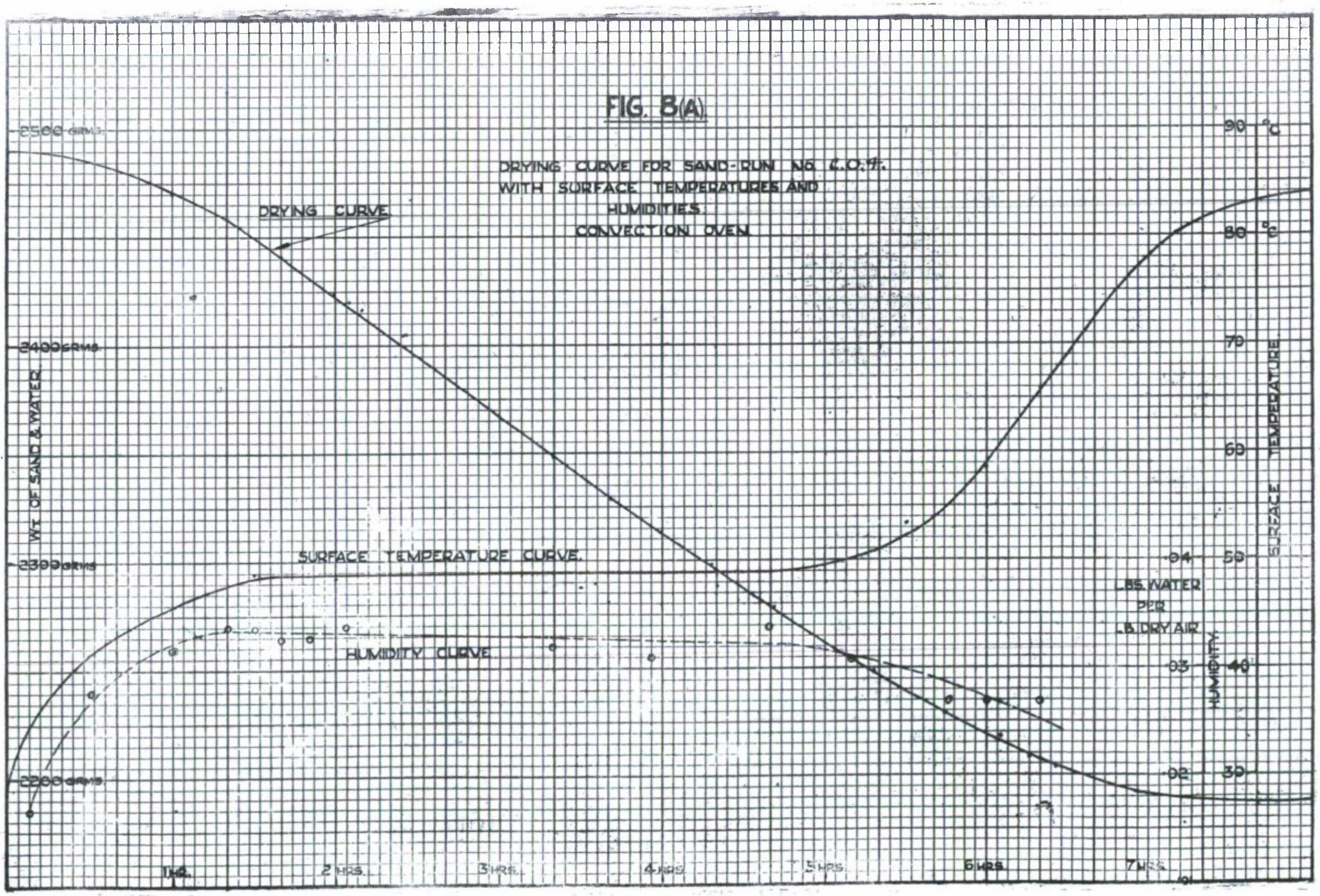


FIG. 8(A)

DRYING CURVE FOR SAND - RUN NO. C.O.4.
WITH SURFACE TEMPERATURES AND
HUMIDITIES.
CONVECTION OVEN.

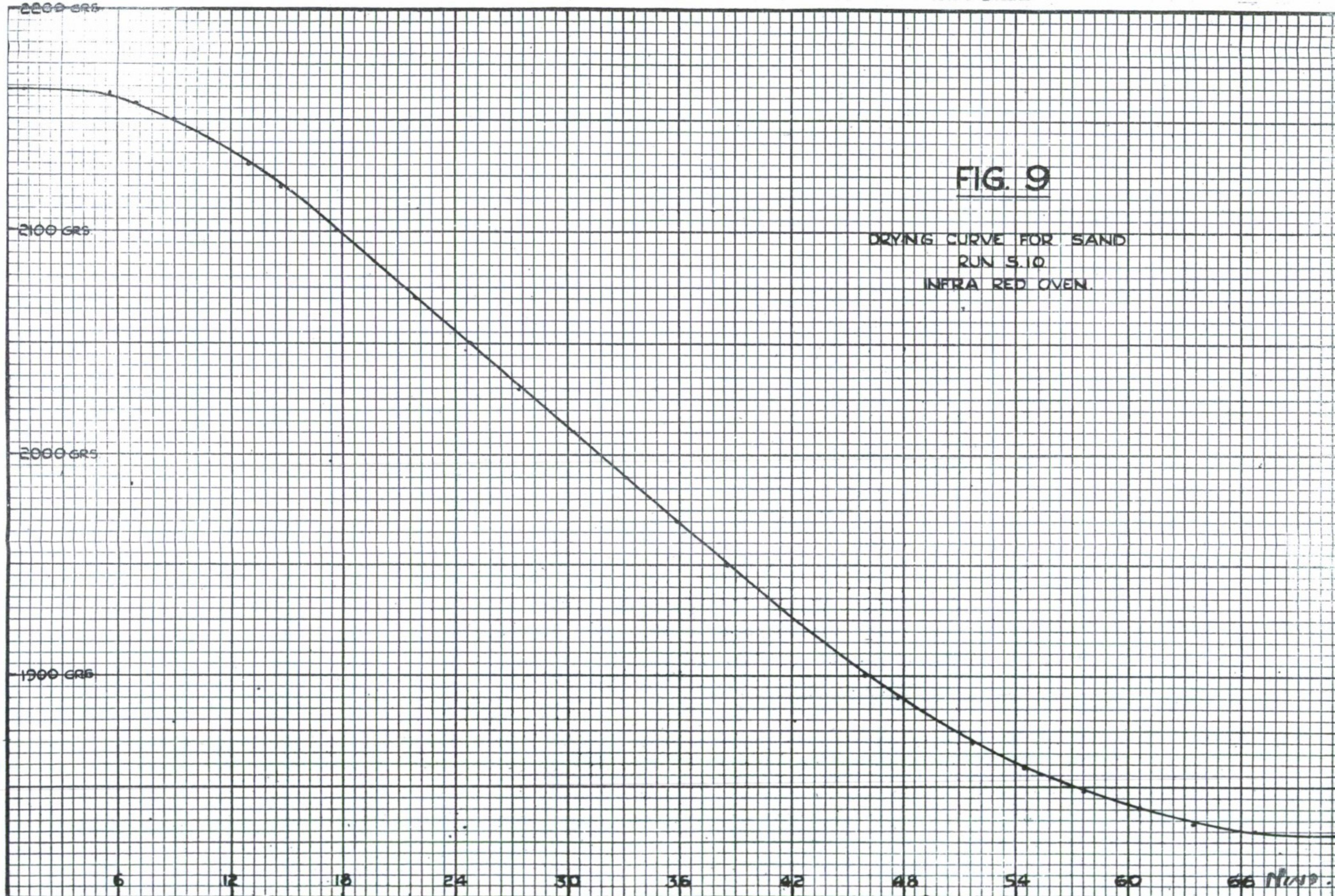
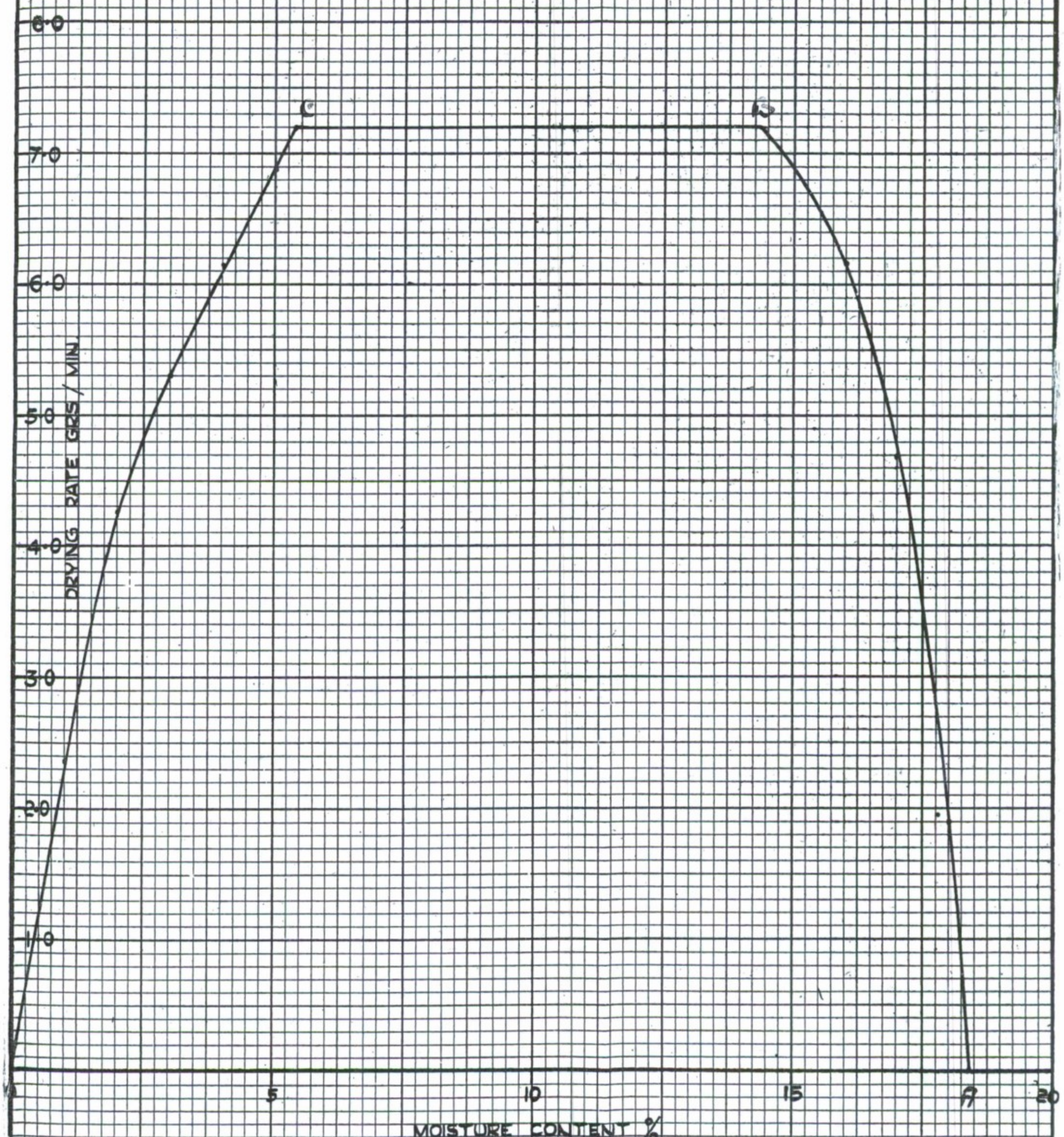


FIG. 9

DRYING CURVE FOR SAND
RUN S.10
INFRA RED OVEN.

FIG. 10

DERIVED DRYING CURVE FOR
SAND RUN 5. 0
INFRA RED OVEN.



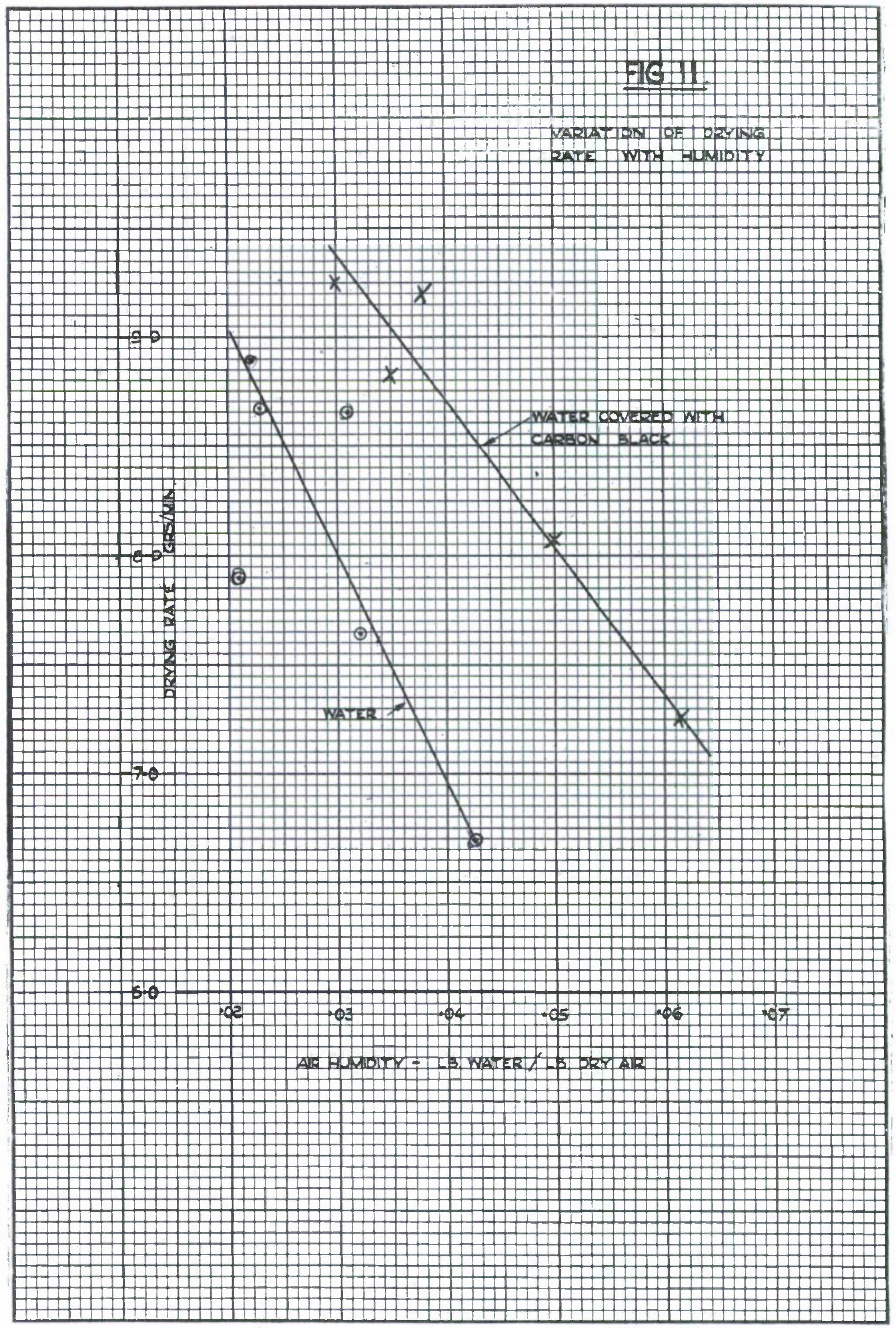


FIG 11.
VARIATION OF DRYING
RATE WITH HUMIDITY
WATER COVERED WITH
CARBON BLACK
WATER
DRYING RATE GRS/MIN.
10·0
8·0
7·0
5·0
·02
·03
·04
·05
·06
·07
AIR HUMIDITY - LB. WATER / LB. DRY AIR

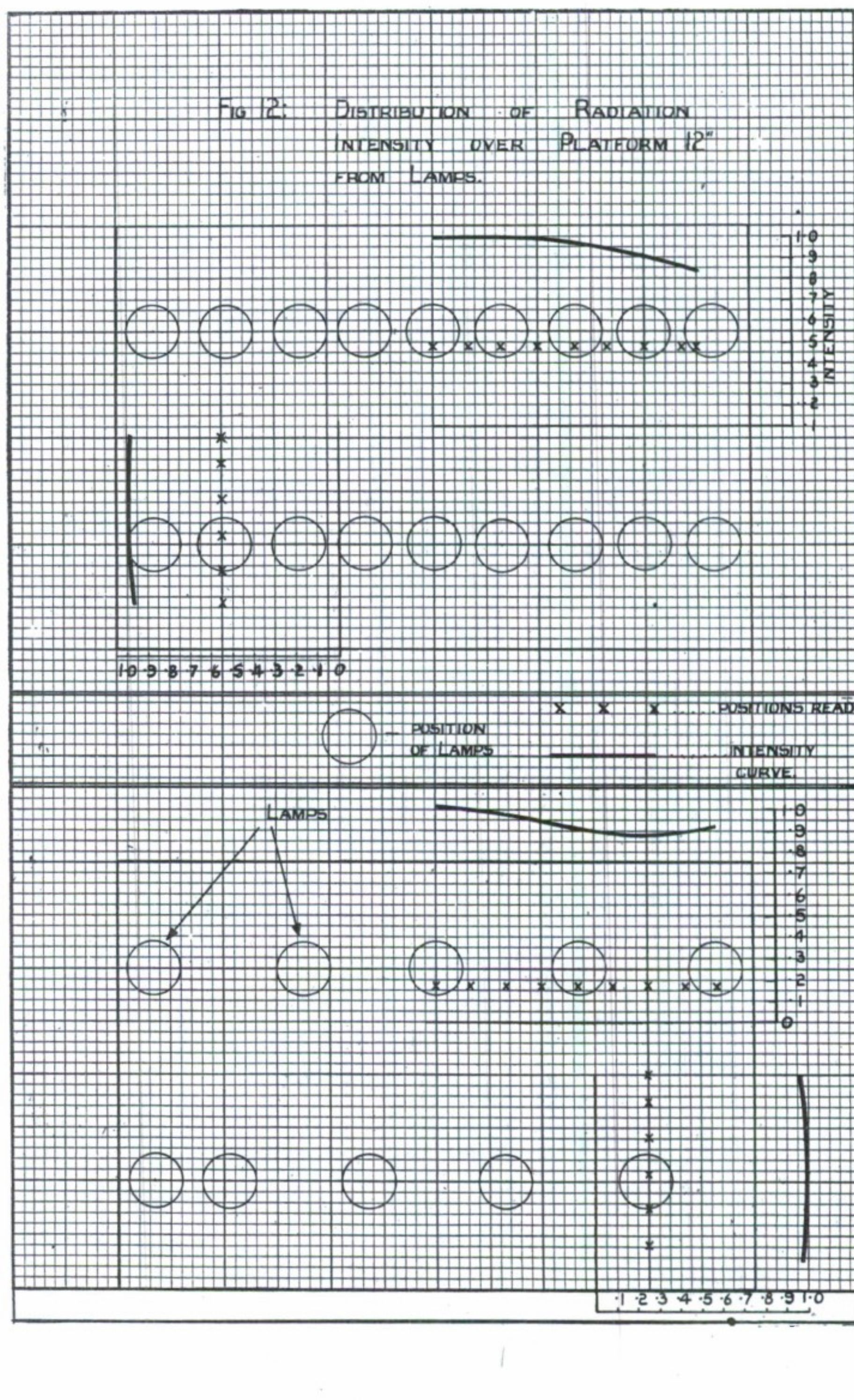


FIG 12: DISTRIBUTION OF RADIATION INTENSITY OVER PLATFORM 12" FROM LAMPS.

Information Centre
Knowledge Services
[dstl] Porton Down,
Salisbury
Wilts
SP4 0JQ
Tel: 01980-613753
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#:
Date of Search: 16 February 2007

Record Summary:

Title: Study of infra-red radiant heating plant in relation to drying, particularly for explosives and propellants
Covering dates 1947 May
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (Department) CRDD 308/R/47
Held by The National Archives, Kew

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